

Effect of microwave and conventional drying process on the drying kinetics and physico-chemical quality of brown shrimp (*Metapenaeus dobsoni*)

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Abstract

The aim of this study was to compare the drying kinetics, proximate composition, instrumental texture and colour profiling of dried shrimp (*Metapenaeus dobsoni*) under open sun drying (30±2°C), solar with electricity backup drying (60°C) and advanced microwave (1000W/60°C) drying techniques. Initially, the drying rate was faster and inversely related to the progress of time. Upon comparison, it was observed that the drying rate was highest in the microwave drying technique compared to solar with electric backup drying and open sun drying. The protein (15.76 to 71.12%), fat (0.39% to 5.96%) and ash content (0.54 to 3.10%) showed an increase as the drying process progressed. Furthermore, the moisture content of the dried shrimp products was observed to be in the range of 9.9 to 12.5%. The water activity of dried shrimp ranged from 0.63 to 0.69. The energy value of fresh shrimp was 70.43 kcal 100 g⁻¹, which increased to 357 kcal 100 g⁻¹ after drying. The hardness decreased during the drying process, while during storage, it showed an increasing trend. Higher redness and lower yellowness were observed for microwave-dried shrimps compared to other drying techniques, indicating superior quality. The study indicated more efficiency for the microwave drying technique with a higher drying rate and yielded a product with superior quality characteristics in terms of colour and texture.



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Introduction

Marine shrimps are a great source of high-quality protein, beneficial lipids and minerals like iron, zinc, copper and vitamin B₁₂. Additionally, it is rich in long-chain PUFA such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The customer perceives that fish and shellfish are nutritious and healthy. Shrimp has an abundance of omega-3 polyunsaturated fatty acids, which have been linked to a lower risk of diabetes and heart disease (Dong, 2001; Kadam and Prabhakaran, 2010; Vilavert *et al.*, 2017). India exported 252,918 t of dried fish worth ₹3,080.92 crores in 2022-23 (MPEDA, 2022-23). The export of dried fish products accounted

for 14.57% in volume and approximately 4.74% in value (MPEDA, 2022-23). Drying is a traditional seafood preservation process that preserves fish by decreasing water activity and inactivating enzymes through moisture removal from seafood products. This process is crucial for inhibiting the growth of bacteria and molds responsible for spoilage or deterioration of fish meat (Duan *et al.*, 2005). It also inhibits microbial activity in shrimp while minimising deterioration in dried shrimp (Tsironi and Taoukis, 2014).

Drying process involves removing moisture from the fish using various drying methods such as air drying, sun drying, solar drying, hot air drying, microwave hot air drying, oven drying and microwave heating (Baslar

et al., 2015). By removing moisture from seafood, drying inhibits the growth of bacteria and other microorganisms that cause spoilage, thereby improving the shelf-life and quality of the product (Gatea, 2011). Different drying processes can have an impact on the quality of shrimp, affecting factors such as colour, flavour, moisture content, texture, microstructure and nutritional value (Deng *et al.*, 2014).

Sun drying is a traditional drying method. With this method, fish are dried under the open sun. During the sun-drying process, moisture evaporates from the fish's surface through the sun's natural heat, which is referred to as the diffusion process (Jain and Pathare, 2007). Sun-drying can cause lower quality end products due to uncontrollable conditions such as unpredictable weather and sunshine, long drying times and poor sanitary conditions. These conditions can lead to insect damage, contamination from airborne dust, bird droppings and feathers and other forms of contamination, which can affect the safety and quality of the final product (Wang *et al.*, 2011). Solar drying is an alternative to traditional sun drying for drying seafood. Solar drying uses a solar dryer to remove moisture from seafood products, providing more control over the drying process. By controlling the drying temperature, humidity and moisture content, solar drying can produce high-quality dried seafood products. Excessive heat in the dryer can cause case hardening of the dried products, which can result in a tough texture and reduced quality (Reza *et al.*, 2009). The use of a solar dryer with controlled conditions, as described by Mohod *et al.* (2014), can help to improve the quality and safety of dried seafood products compared to traditional sun-drying methods.

Microwave ovens have become increasingly popular for food processing applications in recent years. Microwaves are electromagnetic radiation (Soni *et al.*, 2020). The most prominent feature of microwave heating is volumetric heating, which is quite different from traditional heating. With volumetric heating, the materials can absorb microwave energy directly and internally and convert it to heat (Scott, 2012). Microwave drying causes quick absorption of energy by the water molecules, which causes rapid evaporation of the water and results in high drying rates for foods using less energy and a better quality of dried food (Kipcak, 2017). According to the US Federal Communications Commission (FCC), the microwave frequencies used in general industrial and domestic (commercial) applications are 915, 2450 and 5800 MHz (Radoiu, 2020). Microwaves are widely used in food processing, such as microwave food reheating, microwave defrosting, and microwave drying (Chandrasekaran *et al.*, 2013). The main advantages of microwave drying are faster heating, shorter start-up time, energy efficiency, space-saving, selective heating and end products with improved nutritional quality. Microwave drying enhances digestibility due to protein denaturation that occurs due to chemical and physical reactions during drying (Wu and Mao, 2008). Microwave drying is more effective compared to conventional drying because it offers reduced shrinkage, an improved rehydration ratio and energy savings (Duan *et al.*, 2010). Duan *et al.* (2010) used a microwave-hot air combination for drying tilapia fish fillets with microwave power 200 and 600 W, air temperatures of 40 and 50°C and a constant air speed of 1.5 m s⁻¹ and found that the combination of reduced drying time and improved quality. However, there is very limited report on the comparative studies on traditional sun drying, solar and advanced microwave drying techniques. Hence this study was undertaken with the aim of comparing the different drying

techniques for drying kinetics, proximate composition, textural and colour changes in dried shrimp under the open sun, solar cum electric backup and microwave drying.

Materials and methods

The peeled shrimp (*Metapenaeus dobsoni*) of 200/300 grades (number of shrimps per kilogram) were transported from Kochi, Kerala to the laboratory in an insulated box containing ice and fish at ratio of 1:1. The shrimp was immediately washed with chilled water upon arrival at the pilot plant of ICAR-CIFT, Kochi and was then dried using open sun drying, solar cum electric backup drying and microwave methods. The drying conditions for different methods are as follows: Sun drying: Headless, peeled shrimp were exposed to the sun for 10 h, at 30°C and 11 km h⁻¹ air velocity; Solar cum electrical backup dryer drying: Peeled shrimp were dried at 60°C, 2.5-3.5 m s⁻¹ air velocity and 80% relative humidity over 6 h and 30 min; Microwave drying: A microwave dryer (Model MDR-1601-V5, Enerzi Microwave Systems Pvt. Ltd., India) was used to dry peeled shrimps for 2 h and 40 min at 60°C and 1000 watts of microwave power. After drying, the shrimp were immediately packed in an LDPE pouch and stored at room temperature for further analysis at monthly intervals.

Determination of drying kinetics

Moisture content

The moisture content of dried shrimp was calculated as a percentage in both wet and dry conditions using a hot air oven (100±2°C) (AOAC, 2019). The wet moisture content was determined using the formula:

$$Mw (\%wb) = \frac{Wi - Wf}{Wi} \times 100$$

where, Wi = Initial sample weight; Wf = Final sample weight.

Similarly, moisture content on a dry basis was calculated using the formula:

$$Mw (\%db) = \frac{Wi - Wf}{Wd} \times 100$$

where Wi = Initial sample weight, Wf = Final sample weight and Wd = Dry matter in the sample.

Drying rate and moisture ratio

The following formula was used to calculate the drying rate (DR):

$$\text{Drying rate (DR)} = \frac{Mt - M_{t-dt}}{dt}$$

where M_t = Initial moisture content, M_{t-dt} = Final moisture content and dt = Time interval

Moisture ratio (MR) was determined using the formula:

$$\text{"Moisture ratio (MR)} = \frac{M}{M_o}$$

where, M_0 = Initial moisture content and M = Moisture content at the time of drying process.

Determination of yield of dried shrimp

The difference in the weight of shrimp before and after drying was used to calculate the yield of dried shrimp:

$$\text{Yield (\%)} = \frac{\text{Weight of shrimp after drying}}{\text{Weight of shrimp before drying}} \times 100$$

Determination of proximate composition

To evaluate the moisture content, a known weight of homogenised shrimp meat was placed in a hot air oven at $100 \pm 1^\circ\text{C}$ for 16 h and the estimated moisture content was expressed as percentage (AOAC, 2019). The crude protein content of the shrimp meat samples was assessed by digesting and distilling them using the Micro-Kjeldahl distillation apparatus. The crude protein content was determined and expressed as percentage by multiplying the total nitrogen content by a conversion factor of 6.25 (AOAC, 2019). Using soxhlet apparatus, petroleum ether ($60-80^\circ\text{C}$ boiling point) was used to extract the crude fat content (AOAC, 2019). The crude fat was calculated and expressed as percentage. The ash content was evaluated in a muffle furnace at 550°C for approximately 5-6 h (AOAC, 2019) and expressed as percentage.

Determination of energy value

The energy value of dried shrimp was calculated using the factors 4.27 kcal g^{-1} and 9.02 kcal g^{-1} for protein and fat respectively and expressed as $\text{kcal } 100 \text{ g}^{-1}$ edible part (FAO, 1989).

$$\text{Energy value (kcal } 100 \text{ g}^{-1}) = (\text{Protein} \times 4.27 \text{ kcal}) + (\text{Fat} \times 9.02 \text{ kcal})$$

Determination of water activity

The water activity of dried shrimp was determined using Aqua Lab instruments (Aqua Lab Series 3L, Decagon Device, Ins. Pullaman, Washington, DC, USA).

Determination of instrumental texture

The texture of dried shrimp was analysed using the universal testing machine (Lloyd Instrument LRX plus, Lloyd Instruments Ltd., Hampshire, UK). The sample was analysed using a 50 mm diameter cylindrical probe and a 50N load cell, and the sample was compressed twice at a speed of 12 mm s^{-1} . The different textural parameters such as hardness (N), chewiness (N), gumminess (N), springiness (mm), adhesiveness (Nmm), stiffness (N/mm) and cohesiveness were measured with double compression of 40% with a trigger force of 0.5 kg. Nexygen software connected within the instrument was used to generate a curve for the sample's deformation because of load (Bourne, 1978).

Determination of instrumental colour

The colour of dried shrimp was determined using the Hunter Lab MiniScan® XP Plus Spectro Colorimeter, Model No. D/8-S (Hunter Associates Laboratory Inc., Reston, VA, USA). The sample was filled

halfway into a circular glass cell (2.5-inch diameter) and it was inserted into the groove to measure the colour. The lightness (L^*) ranged from 0 to 100, while a^* represented redness (+)/greenness (-) and b^* represented yellowness (+)/blueness (-). These parameters were evaluated using a D65 illuminant and a 10 standard observer (Papdakis *et al.*, 2000). The whiteness index, chroma, hue angle and browning index were calculated using equations (1-4). The delta E was calculated as the total of the colour differences between the L^* , a^* and b^* using Equation (5).

$$\text{Chroma (C)} = \sqrt{a^{*2} + b^{*2}} \dots\dots\dots(1)$$

$$\text{Hue angle (h)} = \tan^{-1} (b^*/a^*) \dots\dots\dots(2)$$

$$\text{Whiteness index (WI)} = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \dots\dots\dots(3)$$

$$\text{Browning index (BI)} = [100 (X - 0.31)] / 0.17 \dots\dots\dots(4)$$

$$\text{where, } X = (a^* + 1.75 L^*) / (5.645 L^* + a^* - 3.012 b^*)$$

$$\Delta E = [(L_0 - L^*)^2 + (a_0 - a^*)^2 + (b_0 - b^*)^2]^{1/2} \dots\dots\dots(5)$$

where, L_0, a_0, b_0 is the initial value. L^*, a^*, b^* is the final value.

Statistical analysis

The experimental data of dried shrimps were analysed using IBM SPSS version 28.0.0.0, the Statistical Package for Social Science. The mean, standard deviation, and one-way analysis of variance (ANOVA) were performed to analyse the data. Duncan's multiple range test was used to calculate the mean separations, with differences considered significant at 95% level ($p < 0.05$).

Results and discussion

Drying kinetics of shrimp

During sun drying, peeled shrimp (*M. dobsoni*) were dried for 10 h at 30°C and 11 km h^{-1} air velocity. Solar cum electric backup drying technology was performed at a temperature of 60°C , an air velocity of $2.5-3.5 \text{ m s}^{-1}$ and relative humidity of 80% over the progress of 6 h 30 min for peeled shrimp. A similar study was conducted by Jain and Pathare (2007), which reported that prawns and chelwa fish were dried in open sun, with drying times of 14 and 21 h, respectively. Solar drying techniques are simple to use and economically viable due to the high-quality shrimp produced (Oosterveer, 2006). The shrimp were dried in a microwave for 2 h and 40 min at 60°C and 1000 watts of power. Darvishi *et al.* (2013) observed that raising the microwave power decreased the drying durations of sardine fish. The drying kinetics of sun dried, solar cum backup dried shrimp are given in Fig. 1a and b. Microwave drying kinetics are mentioned in Sumit Kumar Verma *et al.* (2024). The moisture content decreased as the drying time progressed and the drying rate increased rapidly over hours at the beginning. As the moisture content in the products decreased, the drying rate also decreased. Microwave drying was the fastest as compared to solar cum electric drying and sun drying. Duan *et al.* (2011) reported that the moisture content of tilapia fillets were reduced with increasing microwave power. The drying of shrimp during this period is entirely controlled by the drying conditions. After all surface moisture has been removed, the second phase of drying begins, in which bound

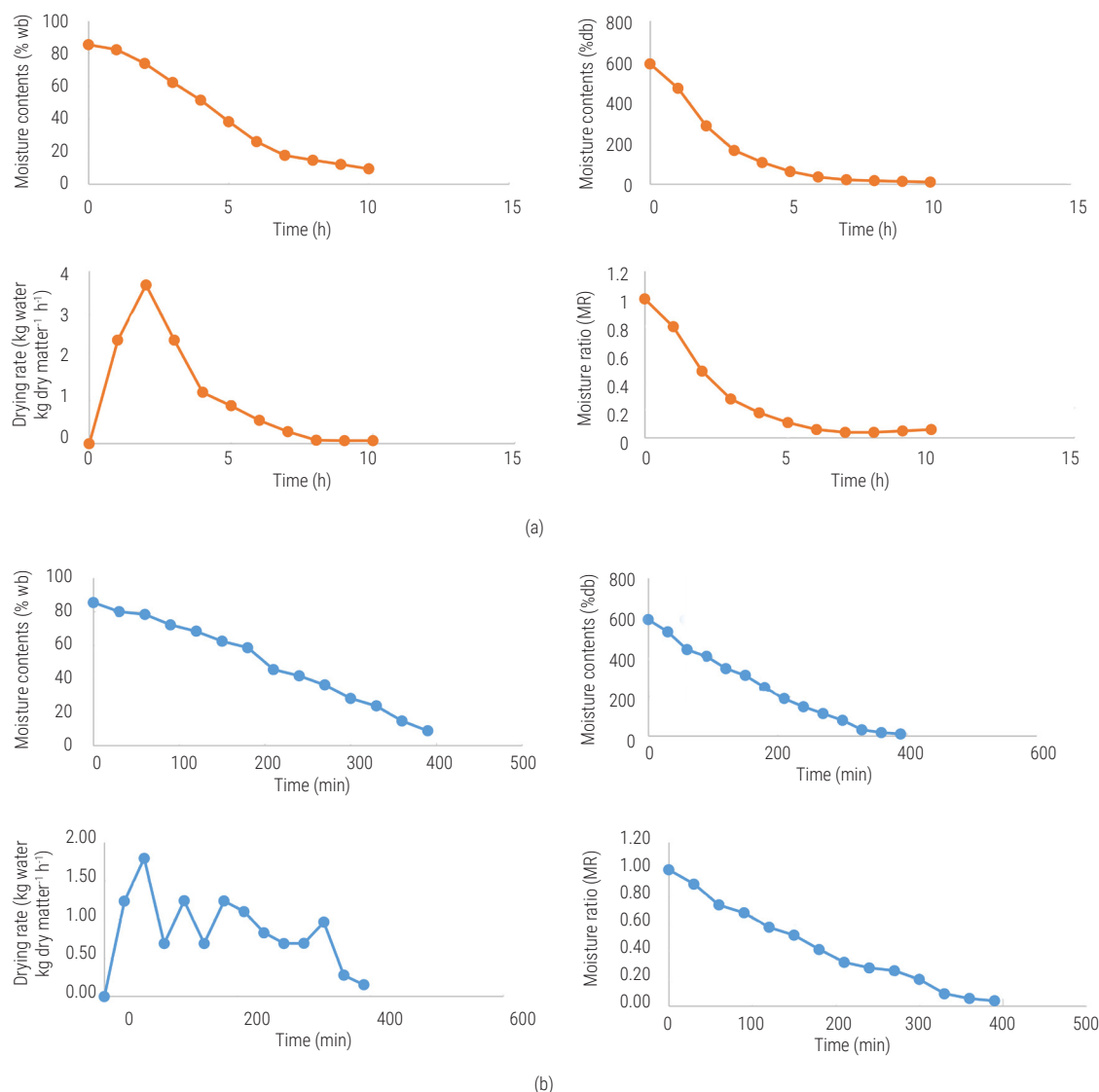


Fig. 1. Drying kinetics of (a) sun dried peeled shrimp and (b) solar cum electric dried peeled shrimp

moisture is removed by the diffusion process, *i.e.* the moisture from internal tissues is brought to the surface of the shrimp.

Ismail and Kocabay (2018) compared the drying kinetics of rainbow trout fillets dried with microwave (90, 180, 270 and 360 W) and infrared (83, 104 and 125 W) dryers and found that comparatively, microwave drying is significantly faster and more efficient in achieving the same moisture level as of infrared drying. Wan *et al.* (2013) studied dried salted grass carp fillets by hot air drying (35 and 45°C), microwave vacuum drying (1 W g⁻¹, 4 W g⁻¹ and 7 W g⁻¹) and found that during vacuum microwave drying, moisture diffusion increased, reducing drying time and oxidation. Wang *et al.* (2011) studied the drying kinetics of tilapia fillets using microwave (150 W, 250 W, 500 W, 700 W and 900 W) and found that as the power of the microwave increased, the effective moisture diffusion and drying time decreased.

A comparison of microwave vacuum drying (600 W) and conventional (convection oven at 55°C) drying of mackerel revealed

that microwave vacuum drying is more efficient, faster and has better sensory and textural attributes (Viji *et al.*, 2019). Pankyamma *et al.* (2021) investigated the quality of marinated boneless tuna cuts dried with a microwave vacuum (600 W, 650 W and 700 W for 2 h), hot air (55°C) and sun drying and found that increasing the microwave power reduced the amount of moisture and water activity in the dried tuna chunk.

Changes in proximate composition in peeled dried shrimp

The moisture content of fresh peeled shrimp was 82.65%, while it dropped to 9.99, 12.95 and 12.25% during the drying processes under the sun (SP), solar cum electric (SEP), and microwave (MP) respectively. The amount of protein (69.76 to 71.12%), fat (2.77 to 5.96%) and ash (2.48 to 3.10%) increased as moisture decreased during different drying methods (Table 1). Murali *et al.* (2021)

investigated the mathematical modeling of drying kinetics and quality of shrimp (*Metapenaeus dobsoni*) dried under a solar-LPG (liquefied petroleum gas) hybrid dryer and reported that shrimp with initial moisture contents of 76.71% were dried to a final moisture content of 15.38% within 6 h of drying. According to Wang *et al.* (2018), vacuum microwave drying of fish fillets increased the protein content to 84.5% and the fat content to 5.45%. According to Wu and Mao (2008), microwave drying increased the protein (69.20%), fat (5.56%) and ash (4.28%) content of carp fillets. The protein, fat, and ash content of the shrimp, mackerel and sardines increased correspondingly as a result of the water loss after drying (Murali *et al.* 2021).

Yield and drying time of dried shrimp

The peeled shrimp were dried under the open sun at 30±2°C and an air velocity of 11 km h⁻¹ for 10 h and the final yields was 21.2% (Table 1). The yield was 23% for peeled dried shrimp dried using solar cum electric backup drying technology at 60°C, air velocity of 2.53.5 m s⁻¹ and relative humidity of 80% for a period of 6 h 30 min. According to Murali *et al.* (2021), a solar LPG dryer achieved shrimp drying within a time frame of 6 h. Murali *et al.* (2019) reported that Indian mackerel dried in a solar hybrid dryer took 8 h for complete drying. The peeled shrimp were dried in a microwave for 2 h 40 min at 60°C and 1000 watt power with a yield of 24% for the final product (Table 1).

Changes in water activity in peeled dried shrimp

The water activity of peeled dried shrimp under different techniques was 0.63 to 0.69, while fresh peeled shrimp had a water activity

of 0.99 (Table 1). The lower water activity inhibits the growth of microorganisms thereby enhancing the shelf life of the products (Qiu *et al.*, 2019). The water activity of dried foods is an essential quality characteristic for evaluating the spoilage of dried foods. The ideal water activity for microorganism growth is 0.98-0.99, although most bacteria stop growing at water activity of 0.90 and lower (Sen, 2005).

Changes in texture of peeled dried shrimp

Texture is an important sensory quality attribute that determines consumer acceptability (Monaco *et al.*, 2008). It is a complex attribute that includes various parameters such as hardness, gumminess, cohesiveness, springiness, stiffness, and chewiness. Texture profiling of peeled shrimp and peeled dried shrimp are given in Table 2. Hardness 1 and 2 of fresh whole shrimp were 20.09 and 16.20, respectively (Table 2). During sun-drying (SP), solar-cum-electric (SEP), and microwave drying (MP), hardness 1 decreased to 1.42, 6.39 and 6.76, respectively. However, during storage, the hardness value for shrimp dried using various techniques increased. Wang *et al.* (2013) also observed that microwave drying decreased the hardness of fish slices from silver carp at different temperatures and powers. Hardness 1 increased with storage time to 39.32, 17.84 and 2.17 for SP, SEP, MP dried shrimp, respectively (Table 2). Shrimp hardness increased during storage as a result of aggregation and water loss caused by the denaturation of the myofibrillar fraction (Bindu *et al.*, 2013). The cohesiveness increased after drying and also during the storage period. MP dried shrimp had the highest cohesiveness. The gumminess and chewiness of SP, SEP and MP dried shrimp increase after drying.

Table 1. Proximate composition of dried peeled shrimp (*M. dobsoni*)

Drying methods	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Energy value (K cal 100 g ⁻¹)	Water activity	Yield (%)
FS	82.65±0.06 ^b	15.76±0.14 ^a	0.39±0.05 ^a	0.54±0.00 ^a	70.43±0.55 ^a	-	
SP	9.99±0.74 ^a	69.76±0.09 ^b	2.77±0.01 ^b	3.10±0.56 ^c	322.85±5.81 ^b	0.63	21.2
SEP	12.51±3.66 ^a	70.30±0.00 ^c	4.54±0.06 ^c	2.72±0.11 ^{bc}	341.17±6.04 ^c	0.69	23
MP	12.25±2.31 ^a	71.12±1.38 ^c	5.96±0.07 ^d	2.48±0.02 ^b	357.48±6.34 ^d	0.63	24

*Mean±SD (n=3). Values bearing different superscripts in the same column for each attributes are significantly different (p<0.05)

FS: Fresh peeled shrimp; SP: Sun dried peeled shrimp; SEP: Solar cum electrical dried peeled shrimp; MP:- Microwave dried peeled shrimp

Table 2. Texture profiling of dried peeled shrimp (*M. dobsonii*)

Batch reference	Hardness1 (N)	Hardness2 (N)	Cohesiveness	Springiness (mm)	Gumminess (N)	Chewiness (Nmm)	Adhesiveness (Nmm)	Stiffness (Nmm)
FS	20.09±4.09 ^{ab}	16.20±2.44 ^{ab}	0.23±0.01 ^{ab}	1.00±0.04 ^{ab}	0.47±0.09 ^a	0.14±0.25 ^a	0.14±0.25 ^c	2.68±0.53 ^a
SP	18.67±10.21 ^{ab}	15.29±7.61 ^{ab}	0.23±0.04 ^{ab}	1.05±0.03 ^b	4.58±3.34 ^{abcd}	4.85±3.62 ^{ab}	-0.14±0.06 ^{ab}	41.88±24.05 ^{abc}
SEP	13.70±7.74 ^{ab}	10.06±6.99 ^{ab}	0.20±0.18 ^a	0.60±0.16 ^a	2.26±1.52 ^{ab}	1.46±1.19 ^{ab}	-0.06±0.05 ^{abc}	40.86±7.24 ^{abc}
MP	16.33±4.97 ^{ab}	14.30±5.29 ^{ab}	0.55±0.04 ^d	0.98±0.10 ^{ab}	9.07±3.04 ^{bcd}	8.72±2.30 ^{ab}	-0.03±0.03 ^{abc}	78.00±26.88 ^{bcd}
SP-1	12.78±7.96 ^a	8.83±8.56 ^a	0.27±0.19 ^{abc}	1.22±0.14 ^b	3.89±4.69 ^{abc}	4.89±6.04 ^{ab}	-0.16±0.10 ^{ab}	61.45±65.20 ^{abcd}
SEP-1	53.23±7.26 ^c	47.13±9.94 ^c	0.22±0.06 ^{ab}	0.88±0.04 ^{ab}	11.75±2.62 ^d	10.36±2.74 ^b	-0.06±0.01 ^{abc}	120.71±25.11 ^d
MH-1	17.53±1.91 ^{ab}	15.66±2.54 ^{ab}	0.27±0.02 ^{abc}	1.80±0.45 ^c	4.78±0.80 ^{abcd}	8.41±1.43 ^{ab}	0.02±0.02 ^{bc}	46.91±13.85 ^{abc}
SP-2	26.39±17.61 ^{ab}	24.01±15.55 ^{ab}	0.27±0.05 ^{abc}	1.01±0.13 ^{ab}	6.47±3.88 ^{abcd}	6.19±3.36 ^{ab}	-0.15±0.08 ^{ab}	61.68±37.31 ^{abcd}
SEP-2	24.30±15.70 ^{ab}	18.44±10.15 ^{ab}	0.40±0.09 ^{bcd}	0.85±0.29 ^{ab}	9.70±7.41 ^{bcd}	9.67±10.37 ^b	-0.03±0.04 ^{abc}	31.86±15.47 ^{ab}
MP-2	15.51±8.96 ^{ab}	13.83±8.06 ^{ab}	0.42±0.07 ^{cd}	1.15±0.17 ^b	6.91±4.70 ^{abcd}	8.37±6.58 ^{ab}	-0.06±0.01 ^{abc}	94.06±67.77 ^{bcd}
SP-3	47.99±2.92 ^c	39.73±3.95 ^c	0.21±0.07 ^a	0.93±0.10 ^{ab}	10.26±3.80 ^{cd}	9.26±2.42 ^b	-0.20±0.18 ^a	114.33±9.73 ^d
SEP-3	31.54±5.71 ^b	25.92±5.52 ^b	0.20±0.13 ^a	0.84±0.08 ^{ab}	6.55±4.78 ^{abcd}	5.77±4.74 ^{ab}	-0.03±0.19 ^{abc}	101.38±29.13 ^{cd}
MP-3	18.50±10.11 ^{ab}	16.83±9.53 ^{ab}	0.41±0.02 ^{cd}	1.17±0.43 ^b	7.66±4.33 ^{abcd}	7.83±3.26 ^{ab}	-0.07±0.06 ^{abc}	46.01±8.53 ^{abc}

*Mean ± SD (n=3). Values bearing different superscripts in the same column for each attributes are significantly different (p<0.05)

After drying, the gumminess and chewiness properties were higher in MP dried shrimp; however, during storage, gumminess and chewiness decreased in MP dried shrimp and slightly increased in SP dried shrimp. Springiness was higher for the SP dried shrimp while it increased for the MP dried shrimp during storage. Wei *et al.* (2020) studied the quality of tilapia fillets dried with hot air (40-80°C), microwave (250 W), and hot air-microwave combination drying and observed that the chewiness, elasticity and hardness can be increased resulting in crispy tilapia fillets.

Changes in colour in peeled dried shrimp

Colour profiling of dried peeled shrimp is given in (Table 3). Freshly peeled shrimp had an L* (lightness) of 51.70. The lightness (L*) of dried peeled shrimp increased to 28.76, 25.72 and 10.45 during sun (SP), solar cum electric (SEP) and microwave (MP) drying, respectively. The highest changes in L* (lightness) were observed in sun-dried shrimp (SP) and least in microwave-dried shrimp (MP). The lightness value (L*) of dried shrimp increased to 0.51, 1.74 and 7.83 after 3 months of storage compared to the value immediately after drying in the sun (SP), solar cum electric (SEP) and microwave (MW). Higher changes of L* were observed in microwave dried shrimp (MW) during storage. Wang *et al.* (2018) reported that L* (lightness), redness (a*) and b* (yellowness) increased during hot air drying, vacuum microwave drying, osmosis microwave and osmosis vacuum microwave drying of tilapia fillet.

The redness (a*) of fresh peeled shrimp was 2.43, which increased to 3.49 and 5.54 after the drying processes of solar cum electric (SEP) and microwave (MP) drying, respectively (Table 3), whereas it decreased to 1.21 after the drying processes for sun dried shrimp (SP) compared to freshly peeled shrimp. The redness (a*) of dried shrimp was found to be highest in the microwave (MP) dried shrimp, followed by solar cum electric (SEP) dried shrimp, and lowest in sun (SP) dried shrimp. During storage, it was noticed that the redness (a*) slightly decreased. As compared to the value immediately after drying, the redness (a*) value was lower.

The initial b* (yellowness) value of fresh peeled shrimp was 10.56. Upon undergoing drying processes, the b* values exhibited variations. Specifically, the b* value increased to 2.5 and 12.36 for shrimp subjected to sun-drying (SP) and solar cum electric drying

(SEP), respectively. However, the b* value decreased notably to 1.21 for shrimp dried in microwave (MP) (Table 3). After 3 months of storage, b* values slightly increased by 12.24 and 2.5 for microwave (MP) and sun-dried (SP) shrimp, respectively, while it decreased by 5.38 for solar cum electric (SEP) dried shrimp. Microwave-dried shrimp (MP) exhibited the highest b* changes (yellowing) during storage.

Fresh, peeled shrimp had a chroma value of 10.56, while the chroma value gradually increased by 2.27, 12.83 and 1.51 respectively when the shrimp were dried in the sun (SP), solar cum-electrical (SEP) and microwave oven (MP) respectively. The chroma value of MP dried shrimp and SP dried shrimp increased during storage, while the chroma value of SEP dried shrimp decreased. After 3 months, chroma value of SP and MP dried shrimp increased by 2.45 and 9.95, respectively.

The hue angle for freshly peeled shrimp was 76.76 but increased by 7.78 for the SP dried shrimp and decreased by 1.43 and 28.1 for SEP and MP dried shrimp respectively. Compared to their immediate values for dried shrimp, the hue angle values of the SP, SEP and MP dried shrimp increased by 3.63, 2.89 and 26.65, respectively, after 3 months of storage. After three months, the hue angle of the shrimp was almost identical to that of freshly peeled shrimp. The whiteness index of SP, SEP and MP dried shrimp compared to freshly peeled shrimp increased to 26.06, 16.93 and 9.17, respectively. Among the different types of dried shrimp, MP dried shrimp showed the least change, while SP dried shrimp showed the greatest change in the whiteness index. SEP and MP dried shrimp showed an increasing whiteness index, while SP dried shrimp showed a decreasing whiteness index. The browning index of SEP and MP dried shrimp increased to 14.95 and 0.14, while it decreased for the SP dried shrimp. During storage, the browning index showed a decreasing trend for SEP dried shrimp, while an increasing trend was observed for MP dried shrimp. The major changes in the browning index were observed in MP dried shrimp after 3 months of storage and was 16.75.

During drying, the colour of food materials changes depending on several factors, including pigment degradation as well as enzymatic and non-enzymatic browning (Ling *et al.*, 2015). Wang *et al.* (2013) also observed that a* and b*, chroma, and whiteness increased while

Table 3. Colour profiling of dried peeled shrimp (*M. dobsoni*)

ID/Months	L*	a*	b*	Chroma	Hue°	Whiteness index	Browning index	Delta E
FS	51.70±0.06 ^a	2.43±0.06 ^e	10.27±0.13 ^b	10.56±0.11 ^a	76.76±0.33 ^f	50.56±0.04 ^a	24.63±0.95 ^d	-
SP-0	80.46±0.04 ^f	1.22±0.01 ^d	12.77±0.06 ^c	12.83±0.06 ^c	84.54±0.02 ⁱ	76.62±0.07 ⁱ	18.02±0.11 ^a	28.89±0.03 ^q
SEP-0	77.42±0.42 ^f	5.92±0.01 ^k	22.63±0.25 ^m	23.39±0.24 ⁱ	75.33±0.17 ^d	67.49±0.25 ^f	39.58±0.38 ^j	28.75±0.45 ^f
MP-0	62.15±0.04 ^b	7.97±0.05 ^m	9.06±0.07 ^a	12.07±0.03 ^b	48.66±0.38 ^a	60.27±0.05 ^b	24.77±0.11 ^d	11.89±0.07 ^a
SP-1	81.33±0.06 ^k	0.73±0.03 ^c	17.72±0.01 ⁱ	17.74±0.01 ^g	87.63±0.08 ^j	74.25±0.05 ^j	24.68±0.06 ^d	30.60±0.06 ⁱ
SEP-1	78.90±0.03 ^g	4.77±0.04 ^h	17.51±0.05 ^h	18.15±0.06 ^h	74.77±0.09 ^c	72.17±0.05 ^g	29.07±0.12 ^g	28.25±0.01 ^e
MP-1	73.83±0.10 ^e	6.01±0.04 ⁱ	20.03±0.11 ^j	20.92±0.12 ⁱ	73.29±0.03 ^b	66.50±0.15 ^e	37.10±0.30 ^h	24.45±0.04 ^d
SP-2	80.37±0.01 ⁱ	0.02±0.02 ^a	14.30±0.03 ^d	14.30±0.03 ^d	89.91±0.06 ^l	75.71±0.02 ^k	19.16±0.03 ^b	29.06±0.00 ^g
SEP-2	79.34±0.23 ^h	3.12±0.07 ^f	16.60±0.11 ^f	16.89±0.12 ^f	79.35±0.16 ^h	73.31±0.25 ⁱ	25.91±0.31 ^e	28.37±0.20 ^e
MP-2	68.66±0.04 ^c	5.16±0.03 ⁱ	21.10±0.05 ^k	21.72±0.05 ^j	76.26±0.05 ^e	61.87±0.03 ^c	41.57±0.11 ^j	20.31±0.05 ^b
SP-3	80.97±0.08 ^j	0.49±0.01 ^b	15.27±0.02 ^e	15.28±0.02 ^e	88.17±0.05 ^k	75.60±0.06 ^k	20.86±0.02 ^c	29.76±0.09 ^h
SEP-3	79.16±0.02 ^h	3.60±0.01 ^g	17.25±0.01 ^g	17.62±0.01 ^g	78.22±0.02 ^g	72.71±0.02 ^h	27.45±0.02 ^f	28.35±0.02 ^e
MP-3	69.98±0.08 ^d	5.58±0.08 ^j	21.30±0.09 ^j	22.02±0.11 ^k	75.31±0.14 ^d	62.77±0.12 ^d	41.52±0.32 ^j	21.59±0.28 ^c

*Mean ± SD (n=3). Values bearing different superscripts in the same column for each attributes are significantly different (p<0.05)

hue angle (h°) decreased during air drying, freeze drying, vacuum drying (VD) and microwave-vacuum drying of restructured fish slices from silver carp after drying. The colour change is attributed to the dual effects of Maillard browning reactions and the oxidation of fats during drying (Shi *et al.*, 2008). It was discovered that microwave-dried shrimp had a lower b^* value, whereas solar cum electric drying had a higher value. Wan *et al.* (2012) obtained comparable results for microwave vacuum drying of grass carp fillets. In the VMD process, higher microwave intensity resulted in lower b^* values. It could be explained that a shorter drying time results in lesser colour loss in the VMD process. When compared to hot air and sun drying methods, microwave drying preserved the colour of tuna chunks. The difference could be attributed to the higher degree of denaturation of protein and myoglobin that occurred during an extended drying period in sun-dried and hot air-dried products. Guo *et al.* (2017) noted in his study of microwave processing techniques that the low exposure period reduces the denaturation of myoglobin and other proteins during microwave heating. Similar results were obtained in studies involving microwave vacuum drying of mackerel and squid shreds by Cheng *et al.* (2021). In contrast, Perez-Juan *et al.* (2012) found that raising the power level did not affect the lightness of dried tuna chunks, which might be due to the comparable exposure duration (2 h) given at each power level.

Kipcak and Ismail (2021) used microwave dryers (90-360 W power) to dry fish fillets, chicken, and beef and found that the most dramatic colour change (ΔE) was observed for the chicken during the drying process, as well as the smallest for the fish. Wang *et al.* (2018) found that L^* , a^* and b^* of tilapia fillets increased significantly due to amino acids and sugars involved in the Maillard reaction during vacuum microwave drying. Liu *et al.* (2018) observed that microwave exposure time on tilapia fillets increased Maillard reaction, resulting in a colour change from white to pale yellow. Wei *et al.* (2020) studied the quality of tilapia fillets dried with hot air (40-80°C), microwave (250 W) and hot air-microwave combination drying and observed that colour changes from white to yellow.

Microwave drying technology offers numerous advantages for drying shrimp in comparison to conventional methods. It facilitates a faster drying rate, leading to reduced processing time. Furthermore, microwave-dried shrimp exhibited enhanced quality attributes, including higher protein, fat and ash contents, as well as an increase in energy value, when compared to conventionally dried shrimp. Although there was an initial decrease in hardness, it was noted to increase during storage, although open sun-dried shrimp had higher hardness. Additionally, microwave-dried shrimp showed desirable colour characteristics, however with slight differences from conventionally dried shrimp. Overall, microwave drying emerges as a promising and innovative technique for shrimp drying, offering advanced processing, improved quality and better preservation of nutritional attributes compared to traditional methods.

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